QUICK INSTALLATION/REMOVABLE VHF DF/HOMING SYSTEM FOR LIGHT AIRCRAFT AND SMALL HELICOPTERS

Prepared by

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I. INTRODUCTION

Light aircraft and/or small helicopters provide a fast, highly mobile radiolocation platform. Airborne DF and homing maneuvers can be executed essentially unimpeded in the urban environment in contrast to the heavy restrictions imposed by street traffic on the ground. In addition, a significant increase in system sensitivity accrues (especially at VHF) due to the favorable height/gain function of an elevated receiving antenna.

The cost of airframe modification to accommodate conventional direction finding systems, however, typically exceeds equipment costs by an order of magnitude. Where specially equipped aircraft are not available, DF equipment is needed which can be rapidly installed and removed without airframe modification. This document describes an approach for providing a readily installed DF/homing system for light aircraft and/or helicopters which does not require airframe modification and requalification. The unit can be strapped down and removed as requirements dictate.

II. SYSTEM DESCRIPTION

A. Overall Description

Figure 1 is a block diagram of the proposed system consisting of four units: antenna, receiver, data processor, and left-right meter. The antenna easily mounts external to the aircraft as described below. The receiver can be any available portable equipment. The data processor accepts the receiver IF and drives the left-right homing meters. Frequency coverage of the system would be restricted by antenna design. Antenna design for 20 to 80 MHz, 80 to 170 MHz, or a combination of the two ranges is practical.

B. Antenna and Installation

The coaxial spaced loop antenna is proposed for installation on the light aircraft as shown in Figure 2. Spaced loop DF antennas developed in this laboratory provide 1 μV/m sensitivity from 20-150 MHz, do not have polarization error, and provide a factor of two site error reduction over the conventional dipole (V scan) or simple loop DF antenna. Loop size and weight will not exceed 10" square and 3 lbs for each loop.

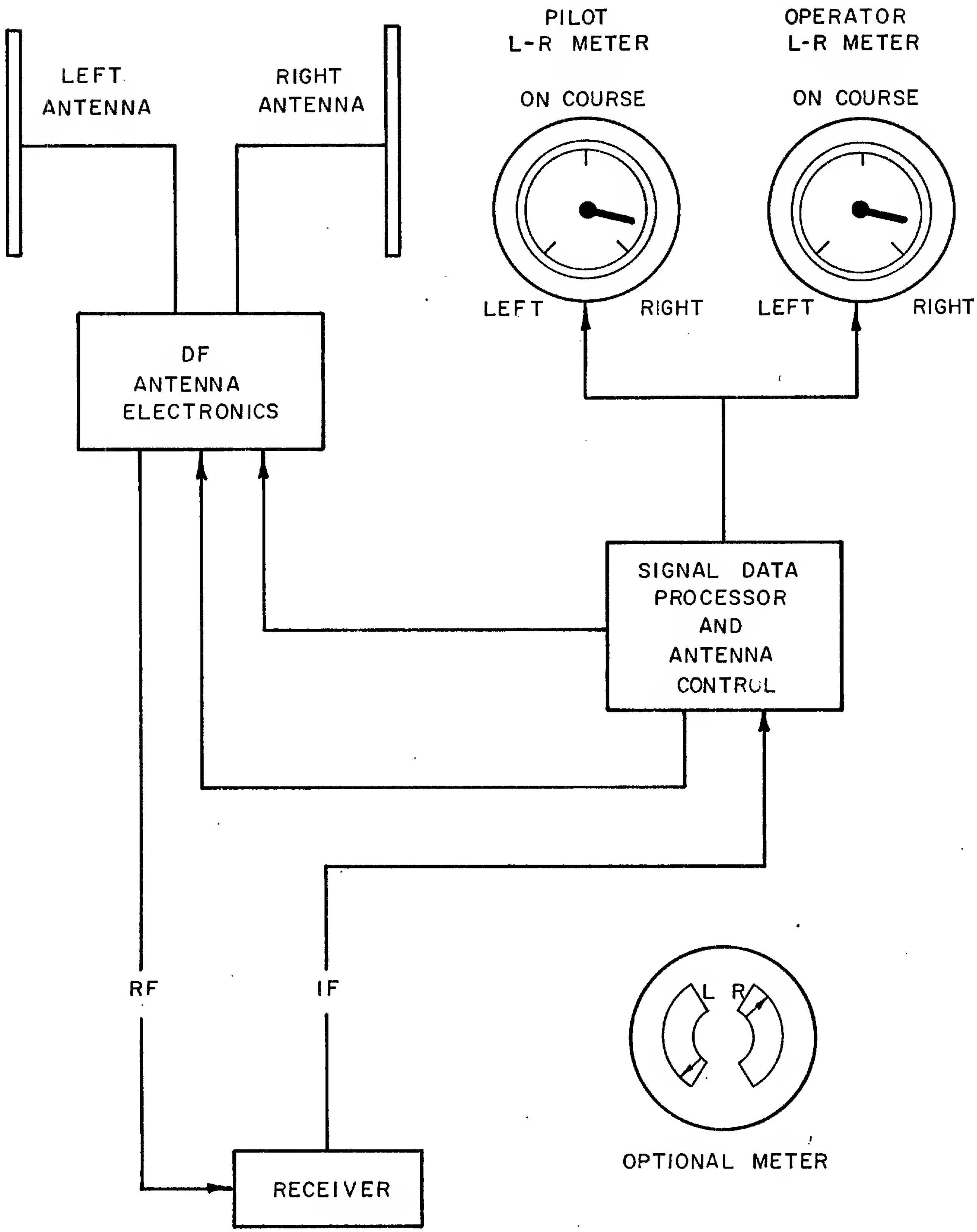

FIGURE I

TENTATIVE BLOCK DIAGRAM OF THE PROPOSED LEFT-RIGHT SYSTEM

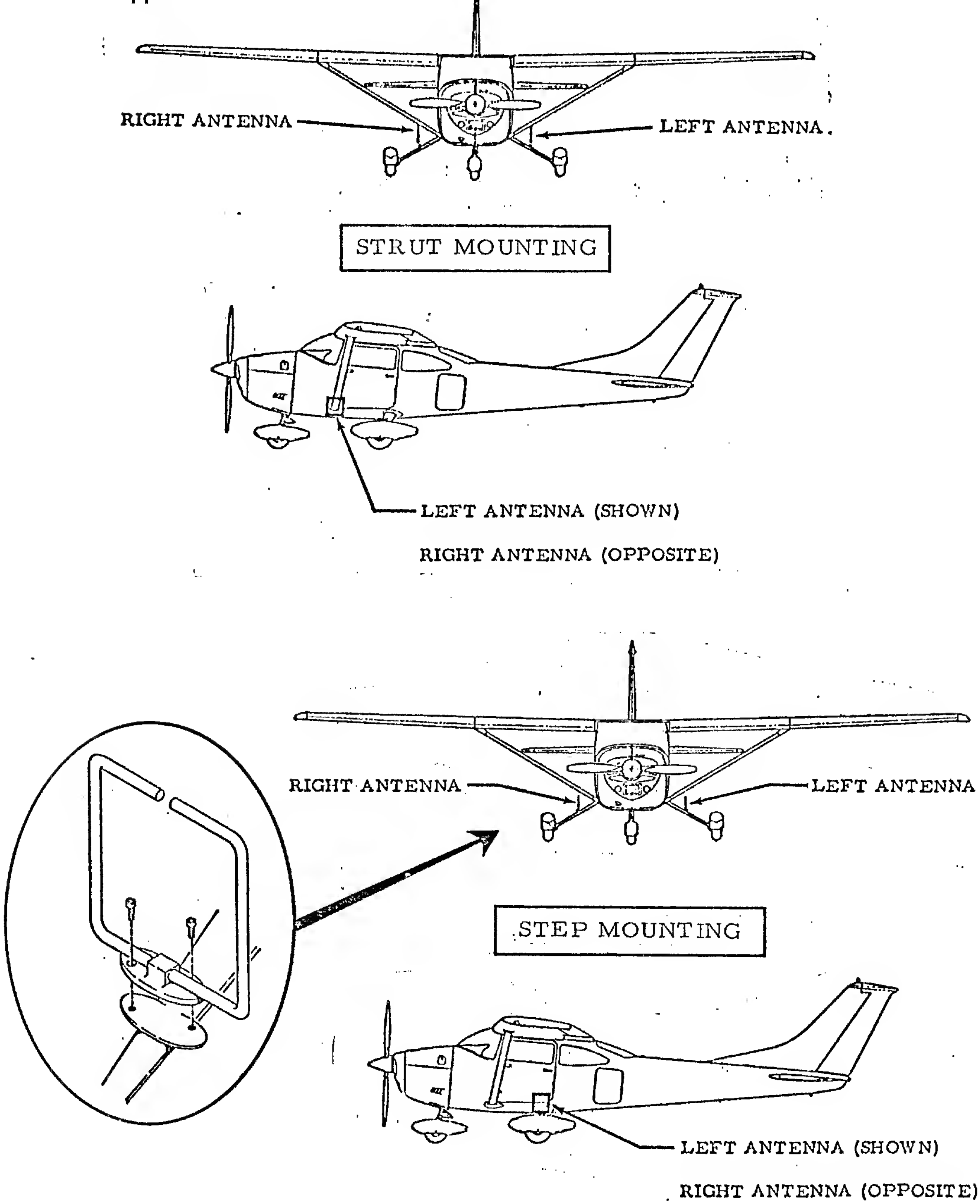

FIGURE 2. QUICK INSTALLATION/REMOVABLE INSTALLATION FOR CESSNA 182

The antenna is designed for simple, reliable installation on aircraft such as Cessna models 150, 172, 177, and 182 or STOL aircraft such as the Helio Courier. With minor change in the installation technique, a practical installation on a small helicopter such as the Bell Model 47 can be achieved as illustrated in Figure 3. Initially, the most economical approach is a single airframe design; however, the antenna can be modified for other airframes for limited additional cost incurred by additional design and flight tests for each airframe.

VHF experience (17) (21)* shows optimum DF performance is obtained with the antenna installed symmetrical to the airframe. Separation from the airframe can be minimized if symmetry is maintained.

The antenna mounting technique uses the landing gear struts of the high wing, fixed gear Cessna type aircraft and the Helio Courier. This mount properly aligns the antenna when the aircraft is airborne but permits full landing gear movement when the aircraft is on the ground. An alternative for appropriate aircraft is to use wing struts to mount the individual loops of the spaced loop array. The helicopter skids as illustrated in Figure 3 or a boom would be utilized to mount the loops.

C. Receiver

Any standard portable VHF receiver is satisfactory. Receiver modification to provide an IF output is necessary if none exists on the standard model.

D. Data Processor

The data processor serves three functions: (a) antenna tuning control, (b) sense network sequencing, and (c) receiver IF output processing to operate the left-right meters. The basic design of previous SwRI work (21) is applicable for the proposed system emphasizing repackaging for quick installation.

E. Left-Right Meters

Prior developments have utilized the left-right meter shown as with the system in Figure 1. More recent work indicates the dual meter illustrated as optional may be easier to use in simplified systems. One left-right meter would be mounted on the data processor. A second left-right meter should be located for convenient use by the pilot.

*Numbers in parentheses refer to Section IV. References.

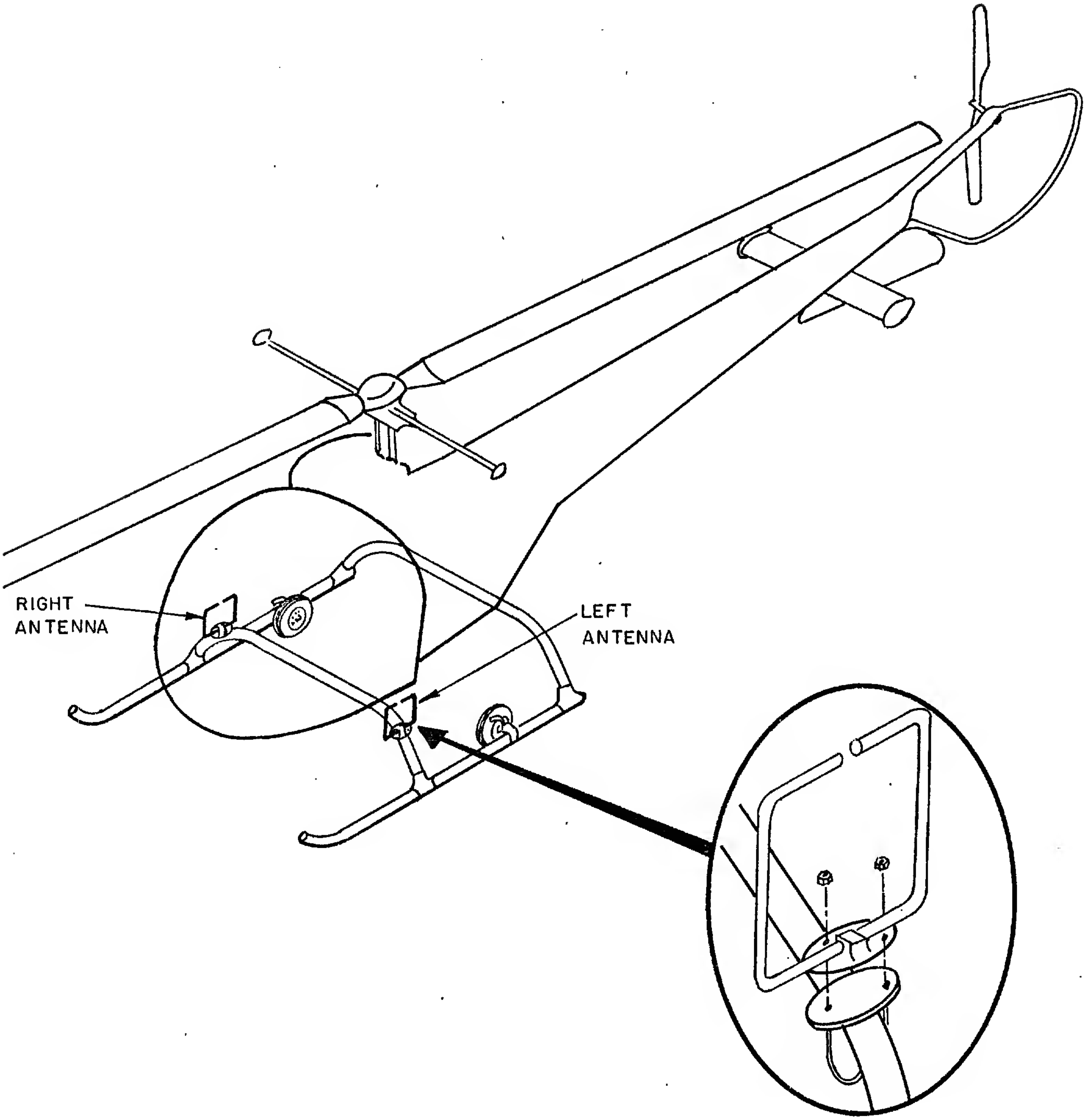

FIGURE 3

QUICK INSTALLATION / REMOVABLE
INSTALLATION FOR LIGHT HELICOPTER

III. TECHNICAL DISCUSSION

A. Previous Airborne VHF Direction Finding Experience

Over the past years, Army cardioid HF and VHF helicopter DF development has been cancelled due to unsuccessful DF performance. The cancelled system is very similar in theory of operation to the DF-4 system. Major differences include an array to provide four cardioid patterns rather than three and digital bearing computation rather than an analog readout. The failure of this DF system on the helicopter occurred for two basic reasons: (a) polarization error and (b) the dependence of DF accuracy on correct phase and amplitude injection from the sense antenna in a complex airframe environment.

This laboratory has performed system development in the VHF airborne antenna field (17) (23) with applications in intercept and DF on signals of unknown polarization. Early work considered only vertical polarization as is often used in two-way communications systems in the VHF frequency range.

Experience has shown that a DF antenna designed for vertical polarization is inadequate for airborne VHF since the transmitted polarization is not always vertically polarized. Airframe reradiation and the propagation environment also contribute to polarization error. The spaced loop antenna offers an excellent solution for this aspect of the problem by virtue of polarization independent direction finding performance. Furthermore, the use of electrostatically shielded loops greatly reduces error effects traceable to capacitive coupling of the antenna to the airframe.

The use of monopole or electric dipole elements in Adcock or interferometer arrangements requires laborious hand adjustments or calibrations for each installation to eliminate polarization error and/or to balance out capacitive effects. The requirement for hand adjustment for each installation makes dipole DF elements impractical for use on various aircraft. When dipole elements are installed to eliminate these effects; however, the dipole antennas show twice or more the reradiation error of the spaced loop in the same environment (16), (17), (24).

B. Principles of Operation

Figure 4 shows the coaxial spaced loop antenna with parallel opposition connection. DF performance is obtained by rotating the spaced loop until the plane of incidence is perpendicular to the loop axis (interference null). Although the antenna pattern changes in shape as a function of polarization, the interference null remains fixed in direction presenting a 180° azimuth ambiguity. Ambiguity resolution independent of polarization can be accomplished in many ways, including the use of a simple loop antenna

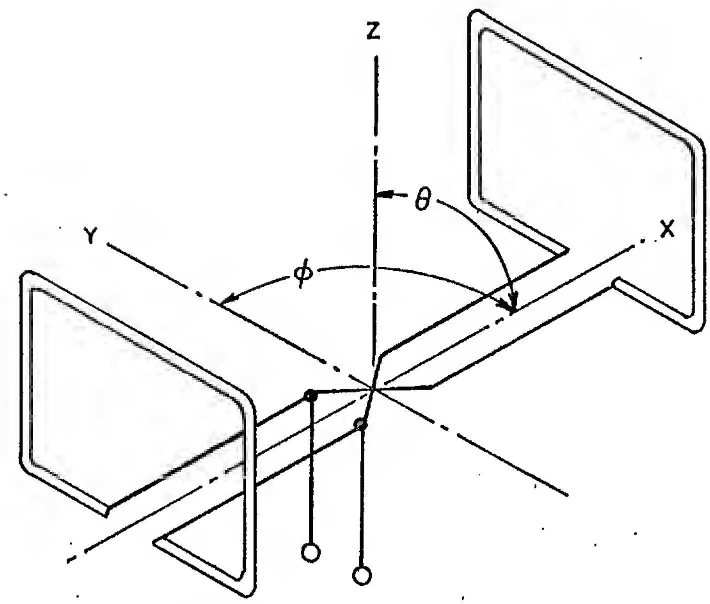

FIGURE 4

PARALLEL OPPOSITION COAXIAL SPACED LOOP

FIGURE 5

AIRBORNE HF SPACED LOOP INSTALLATION

The U. S. Army presently uses the contractor developed spaced loop in the AN/ARQ-27 and the AN/ARD-24, HF left-right DF systems. These versions site the antenna in front of a helicopter as illustrated in Figure 5 and provide excellent bearing accuracy. The systems are designed to provide steering information to the forward bearing. Other sites and smaller versions are feasible.

A block diagram of the AN/ARD-24 system is given in Figure 6. The two spaced loop sense patterns are alternately sampled at a 60 Hz rate. The antenna RF output is fed through the receiver to the signal processor. Bearing information readout is available in three forms simultaneously: on left-right meters, an A-scope, and a strip chart recorder. The second channel of the strip chart recorder is used to record aircraft heading to simplify DF data reduction at a later time. In the proposed application this duplication of system readout is not needed.

A simplified operational block diagram of the AN/ARD-24 system is given in Figure 7. Left-right meters are arranged to read in the same manner as an omni bearing indicator; that is, if the signal is on the right of the aircraft, the meter reads to the right.

C. Redesign for the Proposed VHF System

1. Antenna

This laboratory has developed a series of coaxial spaced loops equivalent to the HF left-right system for use over the 2 to 300 MHz frequency range. Reference (17) describes a rotating spaced loop antenna for fixed wing use up to 80 MHz. Reference (18) covers fixed antennas for use to 150 MHz. More recent work has produced designs to 300 MHz.

For the proposed system, these designs will be used as the basis for a small antenna suitable for mounting on the selected aircraft. The antenna size is not critical and could be quite small; typically, individual loops of the order of ten inches square are adequate with spacing determined by the airframe selected. Smaller ferrite core designs will be considered.

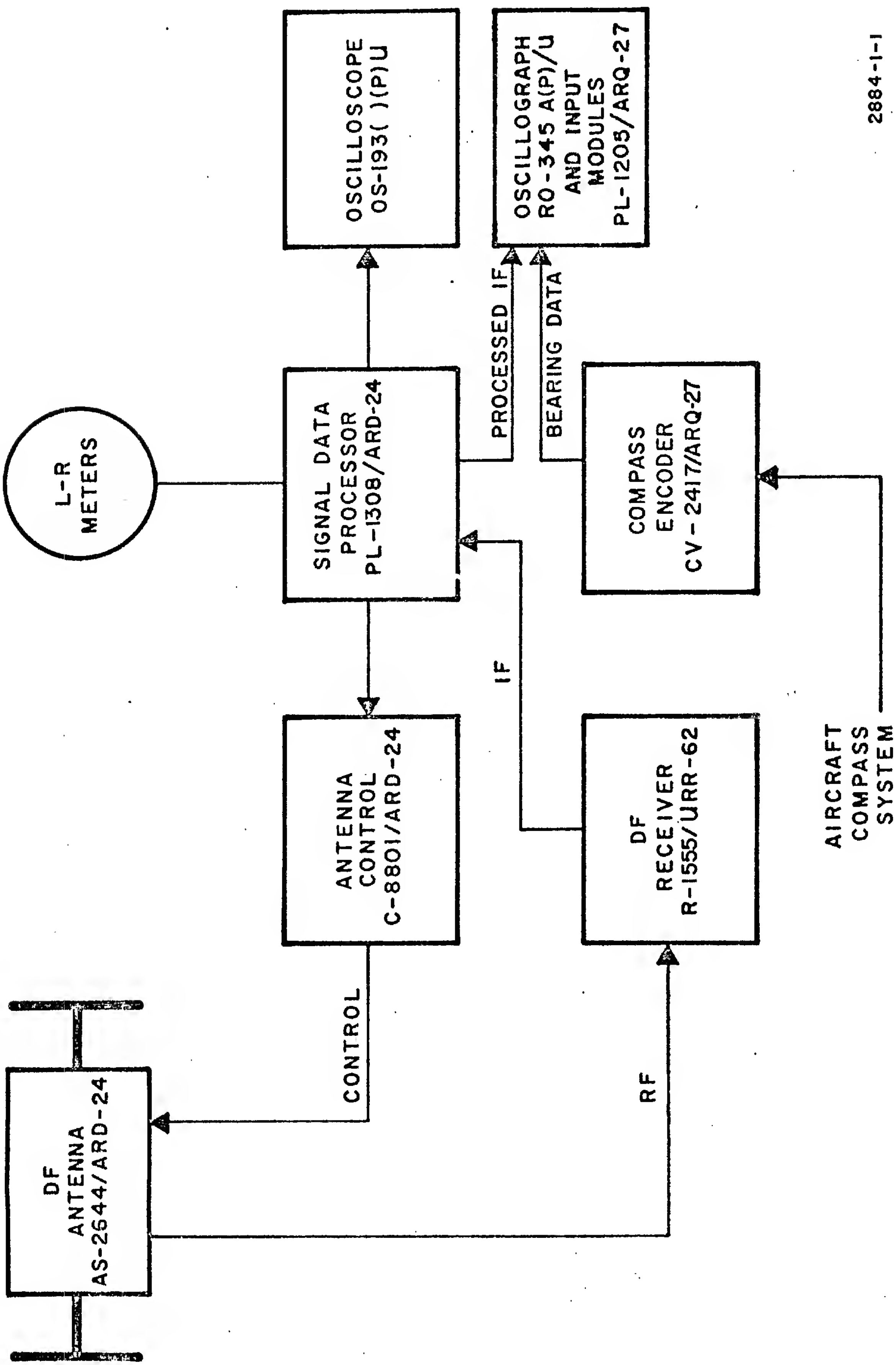

FIGURE 6. SIMPLIFIED DF OPERATION DIAGRAM.

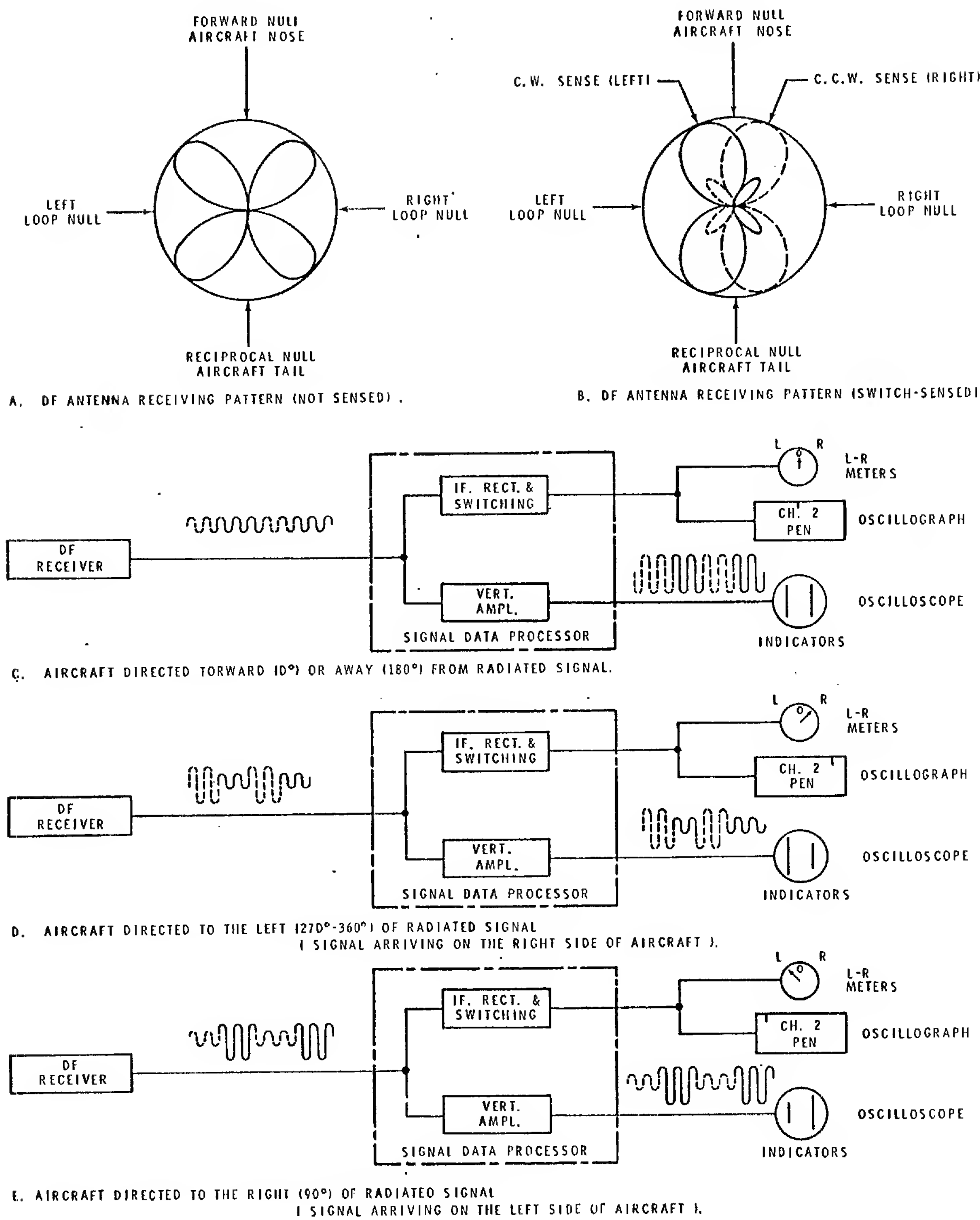

FIGURE 7. LEFT-RIGHT SYSTEM FOR VERTICAL POLARIZATION

2. Data Processor

Data processor basic principles remain unchanged. Certain circuits now using a 455 kHz IF will be redesigned if necessary for the IF frequency of the receiver selected. Minimum redesign is achieved by converting the receiver IF frequency to 455 kHz in the data processor.

Only the left-right meter outputs will be implemented for the model proposed. The design could be compatible with the addition of the strip chart recorder and A-scope at a later time if desired.

D. Brief History of Spaced Loop Antenna

In 1916, a description appeared (1) of a "double framed aerial" which produced figure of eight patterns with "the phases being the same for the two halves of the eight." In current terminology, this description corresponds to a vertical coplanar spaced loop in a vertically polarized field. Increased directivity was justifiably claimed, and detail was provided on the use of a "single frame" to control the antenna pattern; that is, provide sense or ambiguity elimination.

Eckersley (2) described a spaced loop in June 1921, Keen's first descriptions appeared in 1922 (3), and in 1925, Friis (4) reported a receiving system based on a coplanar spaced loop. In these early references the term "spaced loop" was uncommon, and the subject matter usually concerned an application rather than the antenna.

After 1925, polarization error reduction was recognized (5), (6); and, correspondingly, in 1938, Eckersley treated the spaced loop as a special case of an interferometer (7). Keen in 1938 (8) presented simple theory for both coplanar and coaxial versions. Research applications of spaced loops were frequently reported after the mid-1930's (7), (9), (10). In 1939, the large Navy DAB coaxial spaced loop DF was reported (11).

British development of experimental coaxial spaced loops occurred from the late 1930's until the end of World War II and included the first sound theoretical treatment of site error reduction (12), including the elimination of the multivalued error calibration data characteristic of dipole or loop systems. The specific case of shipboard site reradiation error reduction was experimentally demonstrated by 1944 (13), and results published in 1947 by Crampton (14). Aircraft site error reduction was experimentally investigated after 1963 on the basis of the shipboard success.

The Navy sponsored some related HF DF developments in the early 1950's, but military spaced loop development efforts, which had stopped with the DAB, were not resumed until 1955 (15). Navy developments after 1955 were directed toward shipboard problems; Army developments after 1962 became concerned with small tactical designs and led to the first engineering development of the antenna. The latter work has produced both ground based and airborne antennas for HF and VHF, and although reported in detail by Moore (17-22), remains formally unpublished.

At the present (1969-1972), the spaced loop is an extremely important electrically small skywave or polarization independent direction finder for azimuth measurement and site error reduction. Its advantages derive from interferometric characteristics obtained from fixed antenna arrangements suitable for both homing and DF for any signal polarization.

Unfortunately, a thorough and general spaced loop theory has not been published treating sense injection, commutation or switched patterns, testing methods, and related subjects. The development of a partial theory and a basis for optimizing spaced loop designs has for many years been guided primarily by experimental results with familiar arrangements, most based on the coaxial spaced loop with an empirical approach to sensitivity. The discussion presented here does not proceed beyond these limitations. Only a brief theoretical basis will be developed herein sufficient to illustrate soundness of the approach proposed.

E. Selection of Specialized Spaced Loops from General Antennas

A qualitative understanding of the spaced loop antenna can be obtained best by proceeding from the general to the special case. Consider a spaced loop family tree as illustrated in Figure 8. Restricting the discussion to electrically small antennas, cases may be listed (left to right) in increasing order of directivity beginning with isotropic and proceeding toward superdirective elementary antennas. Each case is a mode which may be represented either by arrays of simpler or similar modes or by elementary antennas having that mode as their simplest intrinsic form. The following discussion develops reasons for selecting the design path outlined in Figure 8 for airborne and helicopter applications.

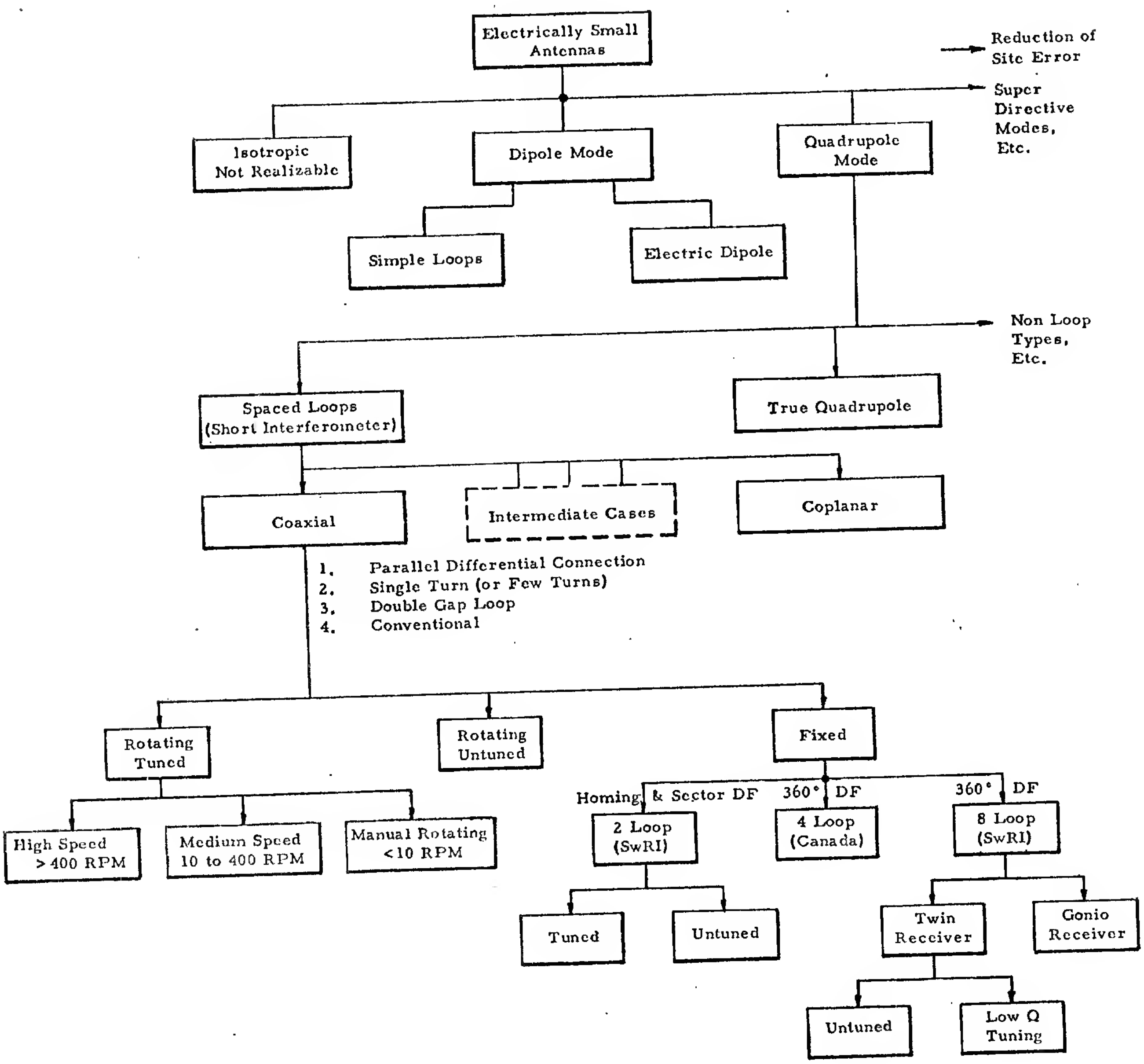

FIGURE 8

ORIGIN OF SPACED LOOP DESIGNS

The isotropic case is not realizable and is mentioned only to convey the idea of a series of modes with increasing directivity. It is not directive and consequently is not a direction finder although it may be simulated by whips, monopoles, etc. for restricted directions or polarizations to serve as an element in a direction finder array.

The dipole mode is visualized as two oppositely phased isotropic sources and represents the simplest realizable antenna and the simplest direction finder. One may think either of electric dipoles* or magnetic dipoles represented by loops. Pairs of electric dipoles may be arranged to form an interferometer which itself may represent the dipole mode. The loop, however, does not well represent the capabilities of the interferometer because of varying response (error) to varying polarization. (The loop may be thought of as two superimposed but conflicting interferometers arranged in different directions.) Single element electric dipole direction finders, including interferometer types, must therefore be used with a single or at least a known polarization; or, as in the Adcock, additional elements must be added. The dipole mode is not capable of relative site error reduction under the restrictions of small antennas since it is the simplest DF arrangement possible.

The quadrupole mode is visualized as two oppositely phased dipoles arranged to suppress the dipole mode in order to reveal the quadrupole or next higher order mode. It is manifested in the spaced loop which is the simplest direction finder which can be constructed entirely from loops and still provide interferometric response independent of signal polarization. The quadrupole mode may be developed as an array of electric dipoles (four are required), an array of loops (at least two are required), or by means of a "quadrupole loop" represented by the category true quadrupole in Figure 8. The true quadrupole loop exhibits a polarization error analogous to,but less than the dipole loop and is similarly not efficiently representative of interferometer capapbilities. The quadrupole mode offers a significant site error reduction capability relative to the dipole mode as has been well reported (15, 16, 24).

If in implementing an engineering design of a direction finder for airborne, mobile, or shipboard use, one adheres to the following two constraints, it becomes evident that the simplest design is a spaced loop:

*Which are the basis of the Yagi, the log periodic, and others.

(1) Electrostatically shielded loops (rather than electric dipoles) are essential to eliminate capacitive balance problems related to airframe coupling.

(2) Response must be independent of signal polarization to eliminate polarization error; that is, an interferometric arrangement must be used.

Condition (1) can be achieved with a single loop, but significant polarization error will result. Condition (2) can be also achieved in a dipole mode antenna which uses electric dipoles, but significant capacitive balance and airframe coupling problems causing error will result. The spaced loop version of the quadrupole mode has been proven to provide both conditions simultaneously. The most suitable spaced loop is the one most readily adaptable to the airframe in question. In a cooperative radiolocation system such as is proposed here, a small fixed tuned antenna can be used.

F. Sensitivity of Spaced Loop Antennas

Electrically small antennas operating in the quadrupole mode normally exhibit relatively low sensitivity in comparison to dipole mode antennas. This can be visualized as a consequence of the double differential connection of receiving elements to obtain the quadrupole directivity. At VHF, however, quadrupole (spaced) loop antennas provide excellent sensitivity of the order of 1 μv/m for 10 dB SNR and 30 kHz bandwidth. Experience with existing helicopter mounted spaced loops and post processing (21) shows good DF patterns are obtained with 30 kHz bandwidth when the receiver audio output is insufficient for accurate message copy. A sensitive audio output to the intercept antenna can be selected to provide the operator with message sensitivity equivalent to DF sensitivity. This sensitivity capability is especially important for SNR/homing applications.

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